Examining the Dynamic Links among Perceived Teacher Support, Mathematics Learning Engagement, and Dimensions of Mathematics Anxiety in Elementary School Students: A Four-wave Longitudinal Study

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Highlights

- The perceived teacher support, mathematics learning engagement, and mathematics anxiety of 1796 Chinese children were investigated four times from the 3rd and 6th grades.
- Bidirectional relations between perceived teacher support and learning mathematics anxiety emerged from grades 3 to 6.
- The relations between perceived teacher support and mathematics evaluation anxiety were unidirectional (from mathematics evaluation anxiety to perceived teacher support).
- Mathematics learning engagement mediated the relation between perceived teacher support and mathematics anxiety (including mathematics evaluation anxiety and learning mathematics anxiety).

ABSTRACT

There has been growing interest in the relation among students' perceived teacher support, mathematics learning engagement, and mathematics anxiety in the last decade. Longitudinal models are needed to provide new insights into the role of engagement in mathematics learning. Based on the control-value theory and developmental dynamic bio-psycho-social model of mathematics anxiety, the present study followed 1796 students from Grades 3 to 6 to investigate the longitudinal associations among perceived teacher support and two conceptually distinct dimensions of mathematics anxiety (i.e., mathematics evaluation anxiety and learning mathematics anxiety). We further explored the potential mediator effects of mathematics learning engagement between perceived teacher support and mathematics anxiety. We found bidirectional longitudinal associations between teacher support and learning mathematics anxiety from Grade 3 to grade 6, as well as unidirectional longitudinal associations between teacher support and mathematics evaluation anxiety (from mathematics evaluation anxiety to teacher support). Furthermore, mathematics learning engagement mediated the relation between perceived teacher support and mathematics anxiety (including learning mathematics anxiety and mathematics evaluation anxiety). These findings highlight the importance of understanding the dynamic interplay among perceived teacher support, mathematics learning engagement, and mathematics anxiety from a developmental perspective.

Keywords perceived teacher support, mathematics learning engagement,

mathematics evaluation anxiety, learning mathematics anxiety, elementary school students

1. Introduction

Mathematics anxiety refers to the "feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematics problems in a wide variety of ordinary life and academic situations" (Richardson & Suinn, 1972). Mathematics anxiety, as a global phenomenon, has a prolonged impact on international community (for review, see Foley et al., 2017; Maloney & Beilock, 2012; OECD, 2015), mathematics achievement (Barroso et al., 2021; Lichtenfeld et al., 2023), students' life and career choices such that students with higher mathematics anxiety tend to avoid choosing mathematics-related courses and avoiding pursuing mathematics-related careers compared to students with lower mathematics anxiety (for review, see Ashcraft & Krause, 2007). Most of the research on mathematics anxiety has been focused on the end results among adolescents and adults (Ashcraft, 2002; Jamieson et al., 2016; Tomasetto et al., 2021), however, there is a growing body of research showing that students develop mathematics anxiety as early as elementary school (Cargnelutti et al., 2017; Harari et al., 2013; Lichtenfeld et al., 2023; Li et al., 2021). Thus, understanding how mathematics anxiety develops in elementary school is an important goal of this research.

Research suggests that students' achievement emotions are linked to their learning contexts (e.g., Guzmán et al., 2023; Lazarides & Buchholz, 2019) and achievement behaviors (e.g., Li et al., 2021). The control-value theory of achievement

emotions offers an integrative approach to help us understand how mathematics anxiety generally develops (Pekrun et al., 2007; Pekrun, 2017). The theory defines achievement emotions as those directly tied to achievement activities (i.e., activity emotions experienced during learning) or achievement outcomes (i.e., outcome emotions related to success or failure). This theory acknowledges that achievement emotions are affected by distal environmental factor and individual factors. Within the context of mathematics learning, the environmental factor includes the instructions and guidance provided by the teachers in the mathematics classroom and the individual factor includes students' engagement in learning mathematics. In the present study, we examined how developmental changes in environmental and individual factors associate with mathematics anxiety.

1.1. Perceived teacher support and mathematics anxiety

Perception of teacher support is one of the most frequently studied social-relational constructs in school setting. It is defined as the degree of trust students have in their teachers' values and the quality of their interpersonal relationships with their teachers (Ryan & Patrick, 2001). As a form of social support, teacher support consists of affective, cognitive, and autonomous support by providing a balance between structure and autonomy to optimize students' learning while also addressing their individual needs (Patrick et al., 2007). To be specific, affective support is characterized by teachers who care about their students (Assor et al., 2002), cognitive support denotes characteristics of teaching such as providing advice and direct assistance (Chai & Gong, 2015), and autonomy support refers to the amount of

psychological freedom teachers allow students in determining their own behaviors such as supporting students in the pursuit of their own goals (Assor et al., 2002) .

Grounded in control-value theory of achievement emotions (Pekrun et al., 2007; Pekrun et al, 2017), mathematics anxiety, as negative achievement emotions, is influenced by teacher support (a distal environmental factor). Furthermore, mathematics anxiety is expected to act back on teacher support. That is, teacher support and mathematics anxiety are thought to be linked by reciprocal causation over time. There is empirical evidence that the quality of affective, cognitive, and autonomous support provided by teachers influences students' emotions. For example, it has been found that students who reported higher teacher support were likely to report higher academic enjoyment (Lazarides & Buchholz, 2019; Liu et al., 2018; Sakiz et al., 2012), lower academic hopelessness (Sakiz et al., 2012), and lower anxiety (Lazarides & Buchholz, 2019) while directly controlling teacher behaviors have negative effects on students' achievement emotions (Assor et al., 2005). The quality of teacher mathematics instructions is negatively related to mathematics anxiety (Kunter et al., 2013; Ramirez et al., 2018). These empirical findings indicate a clear negative association between teacher support and students' mathematics anxiety. However, most studies investigate the relation between teacher support and mathematics anxiety from a cross-sectional perspective and whether the relation is consistent and reciprocal across time has yet to be considered. Further, most of what is known about teacher support has been derived from observations of middle and high school settings (Hospel & Galand, 2016; Martin & Collie, 2019; Sakiz et al.,

2012), examinations of the relation between teacher support and mathematics anxiety among elementary school students are rare (Li et al., 2021; Liu et al., 2018). Thus, the first aim of the current study was to test the reciprocal relations between teacher support and mathematics anxiety among elementary school students using a longitudinal design.

1.2. The mediator between Perceived teacher support and mathematics anxiety: Mathematics learning engagement

According to control-value theory of achievement emotions (Pekrun et al., 2007; Pekrun et al., 2017), mathematics anxiety is also influenced by individual factors beyond environmental factors. The developmental dynamic bio-psycho-social model of mathematics anxiety also posits that mathematics anxiety, as maladaptive symptoms, is a dynamic interplay between environmental and individual factors (Rubinsten et al., 2018). Students' learning engagement is viewed as a robust predictor of adaptive behaviours (for reviews see Skinner et al., 2022; Wang et al., 2019). Learning engagement can be broadly defined as the quality of children's participation in or involvement with learning activities (Skinner et al., 2022). Mathematics learning engagement is a positive state of mind, characterized by absorption, vigor, and dedication on mathematics learning (Chai & Gong, 2015). Multiple facets of engagement can manifest in on-task behaviors, thoughts, and affective states during mathematics learning (Wang & Degol, 2014; Wong & Liem, 2022). More specifically, mathematics learning engagement involves three main dimensions: behavioral engagement (e.g., "I keep trying even if something is hard."),

cognitive engagement (e.g., “ I try to connect what I am learning to things I have learned before.”), and affective engagement (e.g., “I feel good when I am in math class.”).

A growing number of studies have documented that learning engagement can promote positive gains in study (Archambault et al., 2009; Pitzer & Skinner, 2017). However, the direction of the relation between mathematics learning engagement and mathematics anxiety remains unclear. Some researchers suggested that mathematics learning engagement influences mathematics anxiety (e.g., Passolunghi et al., 2020). For example, intervention studies have shown that mathematics anxiety can be reduced by enhancing students’ mathematics learning engagement through cognitive tutoring (Supekar et al., 2015) and mathematics strategy training (Passolunghi et al., 2020). Behavioral and brain imaging evidence also support the negative link between mathematics learning engagement and mathematics anxiety (e.g., Forster et al., 2015; Reyes et al., 2012). In contrast, other researchers suggested that mathematics emotion influences mathematics learning engagement (e.g., Choe et al., 2019; Luo & Luo, 2022). For example, compared to low-math anxiety individuals, high-math anxiety individuals invested less effort into mathematics coursework (for review, see Ashcraft & Krause, 2007), and they tended to avoid choosing the harder mathematics problems (Choe et al., 2019) and procrastinate on mathematics learning (for review, see Steel, 2007). Taken together, the evidence for the nature of causal relations between mathematics anxiety and mathematics learning engagement is inconclusive. Notably, most of the above studies assessed mathematics learning engagement and

mathematics anxiety at the same time, making it impossible to determine the underlying relation between cause and effect. There were few exploratory longitudinal studies focused on mathematics learning engagement (Welsh et al., 2016) or mathematics anxiety (e.g., Ma & Xu, 2004; Pekrun et al., 2017). Only a few studies examined the predictive role of learning engagement on mathematics anxiety (Passolunghi et al., 2020). Thus, more research is needed to investigate the reciprocal relation between mathematics learning engagement and mathematics anxiety.

An integrative developmental framework for conceptualizing academic engagement (Skinner et al., 2022) and development-in-sociocultural-context model for children's engagement in learning (Wang et al., 2019) posit that social contexts especially interpersonal relationships can influence engagement. Within this context, perceived teacher support influences mathematics learning engagement. There is empirical evidence that the quality of academic and interpersonal support provided by teachers influences students' behaviors towards learning (Martin & Collie, 2019; Ober et al., 2021). For example, a number of studies using elementary school, middle and high school samples have found that students who perceived more teacher support report more engagement and effort in class activities or mathematics classroom (Dietrich et al., 2015; Liu et al., 2018; Reyes et al., 2012; Sakiz et al., 2012). Furthermore, development-in-sociocultural-context model for children's engagement in learning posits that engagement is a dynamic developmental and reciprocal pathway to learning that operates at the nexus of multiple contexts, individual factors and relevant outcomes (Wang et al., 2019). Namely, teacher support influences

mathematics learning engagement, vice versa. Most of the existing studies, however, focused on the relation from teacher support to mathematics learning engagement by using cross-sectional design. Although the relation between teacher support and mathematics learning engagement is unquestionable, the direction of effect is somewhat controversial and requires longitudinal examination.

By reviewing the extant literature above, integrating control-value theory of achievement emotions (Pekrun, 2017) and theory model for engagement in learning (Wang et al., 2019; Skinner et al., 2022), we conclude that mathematics learning engagement is an important internal factors that may mediate the relation between teacher support and mathematics anxiety. Specifically, mathematics learning engagement may mediate the relation from teacher support to subsequent mathematics anxiety or the relation from mathematics anxiety to subsequent teacher support.

1.3. Dimensions of mathematics anxiety

One common view is that mathematics anxiety has multiple constructs or dimensions. More specifically, researchers have identified two dimensions of mathematics anxiety: *mathematics evaluation anxiety* (MEA) that is related to evaluations of mathematics learning or testing situations and *learning mathematics anxiety* (LMA) that is related to the process of learning mathematics (e.g., Geary et al., 2019). The multidimensional view is commonly accepted by many researchers, however, researchers nevertheless treat mathematics anxiety as a unidimensional rather than a multidimensional construct, especially when they are measuring young children's mathematics anxiety (Maloney et al., 2015). In particular, mathematics

anxiety is typically measured by a mean or an overall sum score (Beilock et al., 2010; Maloney et al., 2015). To our knowledge, only a few studies on mathematics anxiety involved its dimensionality and leaded to more nuanced conclusions. For example, Carey et al. (2017) revealed that MEA was higher than LMA for students in grade 4. Calculation anxiety was the strongest predictor of individual differences in a low stakes mathematics assessment (Lukowski et al., 2019), whereas math test anxiety was more strongly associated with a high stakes achievement assessment in mathematics (Wang et al. 2018). Recently, Li and colleagues (2021) found that the influences of teacher support on mathematics anxiety varied by its dimensionality. Specifically, teacher support was significant negative related with MEA and LMA in a cross-sectional study, but reduced subsequent learning mathematics anxiety not subsequent mathematics evaluation anxiety from third to fourth grade. In summary, despite some evidence for the dimensions of mathematics anxiety, overall the evidence is limited.

1.4. Mathematics anxiety in China

Although Chinese students have relatively high mathematics proficiency compared to other countries (e.g., Campbell & Xue, 2001), research on mathematics anxiety in China has shown that students in middle and high schools reported moderated to high mathematics anxiety (Wang & Lu, 2006; Xie et al., 2019). In contrast, there is few research on the development of mathematics anxiety among Chinese elementary school students. More recently, some researchers pointed out that Chinese students from fourth to sixth grade reported mild mathematics anxiety due to

the ongoing escalation of the academic content (such as fraction arithmetic and algebra, more abstract and advanced mathematics concepts) in the elementary school curriculum (e.g., Li et al., 2021; Si et al., 2022; Zhang et al., 2018). Therefore, it is important to further investigate how and why mathematics anxiety develops among the young elementary school students in China. More specifically, in grade 3, most children have developed self-awareness with respect to their own emotions (Wang et al., 2011). Thus, grade 3 may be essential to understand the early development of self-conscious thoughts and emotions, particularly with respect to mathematics. To fully understand the developmental trajectories of mathematics anxiety in China, in the present study, we followed Chinese elementary school students from 3rd to 6th grade using a four-year longitudinal design.

1.5. The present study

Based on the above overview of past research, we derive a developmental version of the control-value theory of achievement emotions (Pekrun et al., 2007; Pekrun, 2017) and dynamic interplay between environmental and individual factors (Rubinsten et al., 2018). Consistent with above model's point of view, mathematics anxiety is a dynamic interplay between individual behavioral (i.e., mathematics learning engagement in this study) and environmental (i.e., perceived teacher support in this study) factors. The dynamic interplay between these factors can either prevent or promote mathematics anxiety. Take perceived teacher support as an example, more teacher support may lead to more engagement. The difference from above model is that the reciprocal relations between environmental factors, individual factors, and

mathematics anxiety depend on dimension and development of mathematics anxiety. For instance, both individual and environmental factors are more closely related to learning anxiety than evaluation anxiety across time due to the situational nature of mathematics evaluation anxiety. In this study, we explored two central questions in regard to the development of perceived teacher support, mathematics learning engagement, and mathematics anxiety for Chinese students from 3rd to 6th grade. Based on prior work, we controlled test anxiety, general anxiety, mathematics performance, and effect of gender in the present study (Ahmed et al., 2013; Geary et al., 2019; Namkung et al., 2019).

First, we examined the dynamic developmental relations between students' teacher support and the two dimensions of mathematics anxiety from 3rd to 6th. We hypothesized that teacher support would have a concurrent relationship with MEA at each wave, rather than a predictive one (Hypothesis 1a), whereas teacher support would be negatively related to LMA both concurrently and predictively over time (Hypothesis 1b).

Second, we investigated the role of students' mathematics learning engagement in the relation between teacher support and mathematics anxiety over time. We expected that high teacher support would not reduce subsequent MEA through students' mathematics learning engagement (Hypothesis 2a), whereas high teacher support would reduce subsequent LMA through high students' mathematics learning engagement in later elementary school (Hypothesis 2b).

2. Method

2.1. Participants

A total of 1796 students were recruited with parental consent from three public elementary schools located in two county towns in the northern part China in grade 3. To access whether the sample size was sufficiently large, a post-hoc power analysis using G*Power 3.1 (Faul et al., 2009) was performed, which revealed an acceptable power level (effect size =0.25, $\alpha = 0.05$, power $(1\text{-}\beta) = 1$). They were tested once a year for four consecutive years (December 2016 - December 2019). Specifically, testing occurred in the winter in grade 3 (Wave 1: $M_{\text{age}} = 8.77 \pm 0.74$ years; 42.15% girls, 57.85% boys), grade 4 (Wave 2: $M_{\text{age}} = 9.76 \pm 0.73$ years), grade 5 (Wave 3: $M_{\text{age}} = 10.76 \pm 0.74$ years), and grade 6 (Wave 4: $M_{\text{age}} = 11.78 \pm 0.74$ years). All children spoke Chinese as their first language.

Information about parents' highest education level was reported by 84.25% of fathers and 84.04% of mothers. These parents were primarily the Han nationality (96.35%) and had a high school degree or lower (69.92% fathers, 69.26% mothers).

Attrition rates were low in the present study. More specifically, 7.93% of the participants dropped out at Wave 2, 2.71% of the participants dropped out at Wave 3, and 1.34% participants dropped out at Wave 4. Little's Missing Completely at Random (MCRA) test showed that data did not deviate significantly from MCAR assumption. No significant differences were found between those with complete versus incomplete data. Thus, full information maximum likelihood method was used to estimate the models as we are confident that our data meet the criteria for missing at random (Enders, 2010).

2.2. Measures

All measures are described in detail below. The three control measures (i.e., general anxiety, test anxiety, and mathematics performance) were collected at Wave 1. Mathematics learning engagement, perceived teacher support, and mathematics anxiety were assessed across four waves from 3rd to 6th grade. Students were tested in two 30-minute sessions during school hours in their classroom. The order of the test administration was random for all four waves. This study was approved by the local ethics committee. After obtaining approval of ethics committee board and local school board, school principals were contacted. Following principal and teacher approval, letters were sent home inviting students to participate.

2.2.1. Perceived teacher support

Students' perceived teacher support was measured using *The Perceived Teacher Support Scale,* a well-validated engagement scale with strong reliability and construct validity (Chai & Gong, 2015; Li et al., 2021). This scale includes three types of teacher support: affective support (7 items, e.g., "I feel comfortable in communicating with my math teacher"), cognitive support (5 items, e.g., "My math teacher encourages and guides me to actively find solutions instead of telling me the answers indirectly"), and autonomy support (5 items, e.g., "During math, I can often make my own decisions about the tasks."). Each item was rated on a 5-point scale. The scale had reliability across the four waves of measurement, with Cronbach's α ranging from 0.88 to 0.95 and MacDonald's ω ranging from 0.88 to 0.95. A confirmatory factor analysis (CFA) was conducted to assess the validity of the 17

items model. The three-factor model had goodness-of-fit indexes as follows: χ^2/df = 4.25, $p < 0.05$, RMSEA = 0.06, CFI = 0.92, TLI = 0.91, and SRMR = 0.04.

2.2.2. Mathematics learning engagement

The well-validated *Mathematics Learning Engagement Scale* (Chai & Gong, 2015) with 13 items was used to measure levels of mathematics learning engagement. This scale includes three types of learning engagement: emotional engagement (4 items), cognitive engagement (5 items), and behavioral engagement (4 items). Each item was rated on a 5-point scale. The scale had satisfactory reliability across the four waves of measurement, with Cronbach's α ranging from 0.82 to 0.85 and MacDonald's ω ranging from 0.85 to 89. A confirmatory factor analysis was conducted to assess the validity of the 13 items model. The three-factor model had goodness-of-fit indexes as follows: χ^2/df = 5.24, $p < 0.05$, RMSEA = 0.06, CFI = 0.94, TLI = 0.92, and SRMR = 0.05.

2.2.3. Mathematics anxiety

A revised version of the *Abbreviated Math Anxiety Scale* (Li et al., 2022) was used. It involves nine items and is divided in two subscales measuring mathematics evaluation anxiety and learning mathematics anxiety. More specifically, five items were used to measure students' learning mathematics anxiety and four items were used to measure students' mathematics evaluation anxiety. Students responded to questions about how anxious they would feel during different situation on a 4-point Likert-type scale, ranging from 1 (low anxiety) to 4 (high anxiety). The scale had reliability across the four waves of measurement, with Cronbach's α and

MacDonald's ω ranging from 0.94 to 0.95. CFA revealed that the two-factor model had goodness-of-fit indexes: χ^2 /df = 3, $p < 0.05$, RMSEA = 0.04, CFI = 0.98, TLI = 0.98 (Li et al., 2022).

2.2.4 General anxiety

Students' general anxiety was measured by a five-item generalized anxiety subscale of the Spence's Anxiety Symptoms among Preschoolers (Spence et al., 2001). Sample items include statements such as the student "spends a large part of each day worrying about various things" and the student "has trouble sleeping due to worrying". Each item was rated on a 5-point scale. The scale had a great reliability: Cronbach's α = 0.77.

2.2.5 Test anxiety

Students' test anxiety was measured by the Sarason's Test Anxiety Scale (Sarason, 1978). Students answered 37 true or false questions that tap anxiety taking place in given testing situations (e.g., "After important tests, I am frequently so tense that my stomach gets upset"). The scale had an excellent reliability: Cronbach's α = 0.99.

2.2.6 Math performance

Lastly, students' math performance was measured by the revised Chinese version of the Applied Problems subtest of the Wechsler Intelligence Scale for Children, WISC-IV (Zhang, 2009). Students solved word problems that increased in difficulty. More specifically, in the first part of the task students heard an arithmetical problem orally presented by an experimenter and then solved the problem. In the second part of the task, students were instructed to read and solve the visually presented problem

themselves. Students were individually tested for approximately 10 to 15 minutes by an experimenter in a quiet area of their school. The total number of correctly completed computations was converted to a standardized score. The internal reliability and test-retest reliability obtained from the standardized WISC-V technical report was 0.86 and 0.83, respectively (Zhang, 2009).

3. Results

Notably, students were recruited from 40 different classrooms. Thus, before testing our hypothesized model, we first conducted multilevel analyses. We also tested measurement invariance across waves. Results showed sufficient measurement equivalence across waves (see Supplementary Materials S3.2).

In the following analyses, a longitudinal cross-lagged structural equation model with cross-lagged paths and T2~T4 within-time correlations fixed to be time invariant was conducted using M*plus* 7.0 (Muthén & Muthén, 1998-2012) to investigate the longitudinal interplay among students' mathematics learning engagement, perceived teacher support and mathematics anxiety. Full information maximum likelihood was used to estimate missing data in all analyses.

3.1. Descriptive statistics

Table 1 shows mean and standard deviations of the variables at each wave of the present study. Because the correlations among the variables were largely consistent across waves, **Table 2** presents an abridged version of these correlations, showing the associations among variables measured at Wave 1 and Wave 4 (see complete correlations among the variables across the four waves in **Table S1**). As shown in

Table 2, in grade 3, perceived teacher support was correlated with all of the other variables, *p*s < 0.001. Similarly, the predictive correlations between perceived teacher support measured in grade 3 and the variables measured in grade 6 (i.e., mathematical learning engagement, MEA, and LMA) except for MEA were all significant, *p*s < 0.05.

Table 1

Means and standard deviations for study variables at each wave.

Variables	Grade level							
	Grade 3 (T1)		Grade 4 (T2)		Grade 5 (T3)		Grade 6 (T4)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. PTS	3.86	0.72	3.74	0.89	3.86	0.88	3.86	0.90
2. MLE	3.85	0.76	3.86	0.77	3.92	0.81	3.84	0.85
3. MEA	2.23	0.77	2.21	0.82	2.19	0.81	2.10	0.83
4. LMA	1.72	0.67	1.68	0.70	1.61	0.70	1.64	0.74

Table 2

Correlations for variables in grade 3 (wave 1) and grade 6 (wave 4).

	1	2	3	4	5	6	7	8
3rd Grade measures								
1. PTS		0.53^{***}	-0.13^{***}	-0.20^{***}	0.15^{***}	0.14^{***}	-0.02	-0.12^{***}
2. MLE	0.52^{***}		-0.13^{***}	-0.17^{***}	0.13^{***}	0.13^{***}	-0.07^{*}	-0.17^{***}
3. MEA	-0.16^{***}	-0.23^{***}		0.53^{***}	-0.04	-0.05	0.07^{*}	0.01
4. LMA	-0.21^{***}	-0.24^{***}	0.57^{***}		-0.08^{*}	-0.08^{**}	0.05	0.10^{***}
6th Grade measures								
5. PTS	0.15^{***}	0.17^{***}	-0.09^{**}	-0.11^{**}		0.55^{***}	-0.29^{***}	-0.44^{***}
6. MLE	0.16^{***}	0.18^{***}	-0.11^{***}	-0.13^{**}	0.55^{***}		-0.40^{***}	-0.51^{***}
7. MEA	-0.05	-0.10^{***}	0.15^{***}	0.09^{**}	-0.31^{***}	-0.41^{***}		0.63^{***}
8. LMA	-0.13^{***}	-0.19^{***}	0.05	0.12^{***}	-0.46^{***}	-0.52^{***}	0.63^{***}	

Note. PTS = Perceived teacher support, MLE= Mathematics learning engagement, MEA = Mathematics evaluation anxiety, LMA =Learning mathematics anxiety. The zero-order correlations are below the diagonal, and the partial correlations controlling for gender, test anxiety, general anxiety, and math performance diagonal are above the diagonal.

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Both of MEA and LMA at each wave were correlated with general anxiety, test anxiety, and math performance, *p*s < 0.05. Moreover, gender was correlated with MEA in grade 5 and LMA in grades 3, 4, and 5, *p*s < 0.05 (see **Table S2**). Thus, in the following analyses, we controlled for the influence of test anxiety, general anxiety,

math performance, and gender in the models.

3.2. Cross-lagged longitudinal models

To examine the bidirectional influences between teacher support and mathematics anxiety over time, we conducted two autoregressive longitudinal cross-lagged path analytic models (see **Fig. 1**). For all models, we controlled for test anxiety, general anxiety, gender, and math performance.

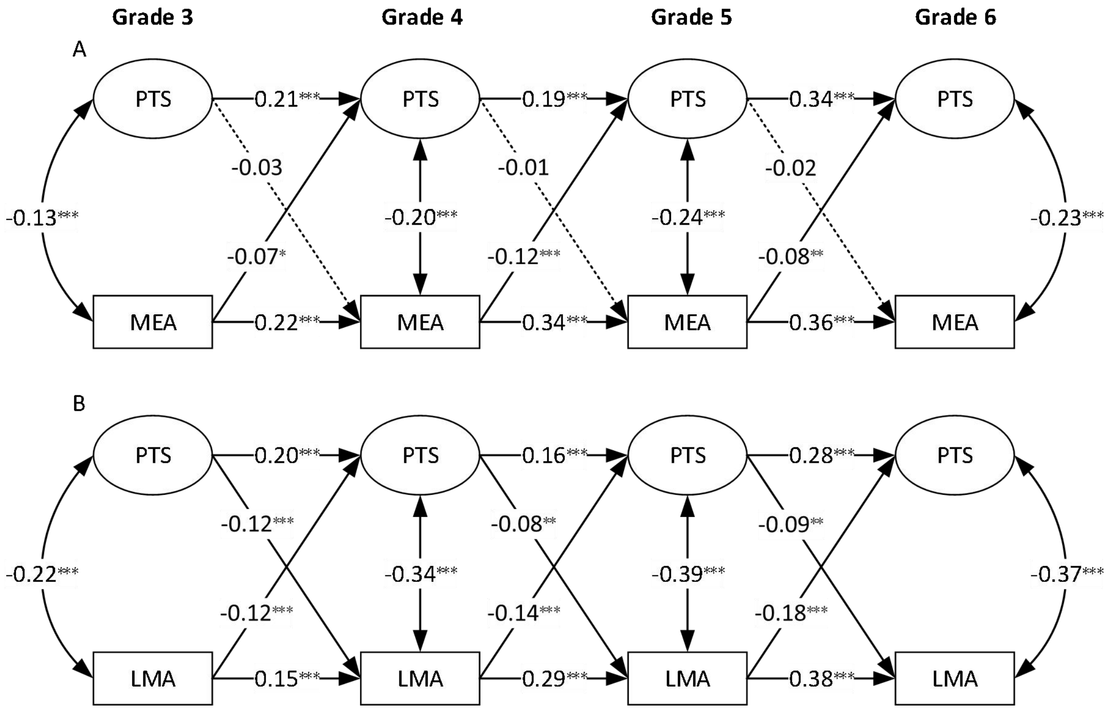

Fig. 1**.** Cross-lagged path models of perceived teacher support and mathematics evaluation anxiety (A), perceived teacher support and learning mathematics anxiety (B). *Note.* PTS = perceived teacher support; MEA = mathematics evaluation anxiety; LMA = learning mathematics anxiety. Dotted lines indicate non-significant paths. Control variables include gender, test anxiety, general anxiety, and math performance. Perceived teacher support is latent variable, with factor loadings ranging from 0.71 to 0.95.

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

3.2.1. The bidirectional influences between teacher support and mathematics evaluation anxiety

We hypothesized that MEA would be negatively related to teacher support

concurrently at each wave (Hypothesis 1a). **Fig. 1A** depicts the cross-lagged associations between teacher support and MEA. The model had a adequate fit, with χ^2 (116) = 961.10, $p < 0.05$, RMSEA = 0.06, CFI = 0.94, TLI = 0.93, and SRMR = 0.07. After accounting for stability paths of teacher support and MEA across consecutive waves, teacher support was negatively correlated with MEA at each wave, βs ranged from −0.24 to −0.13, *p*s < 0.05. Next, we tested the bidirectional paths between teacher support and MEA over time. As expected, we found that teacher support was not related to the subsequent MEA from one wave to another, βs ranged from −0.03 to −0.01, *p*s > 0.05. However, MEA was negatively predicted the subsequent teacher support from one wave to another, βs ranged from −0.12 to −0.07, *p*s < 0.05. Therefore, hypothesis 1a was partially supported such that teacher support was associated with MEA concurrently but not predictively from 3rd to 5th grade. MEA was associated with teacher support both concurrently and predictively over time.

3.2.2. The bidirectional influences between teacher support and learning mathematics anxiety

We also hypothesized that teacher support would be negatively related to LMA both concurrently and predictively over time (Hypothesis 1b). **Fig. 1B** depicts the cross-lagged associations between teacher support and LMA. This model also fitted the data well, χ^2 (116) = 777.04, $p < 0.05$, RMSEA = 0.06, CFI = 0.96, TLI = 0.94, and SRMR = 0.07. Similar to the previous model (**Fig. 1A**), after accounting for stability paths of teacher support and LMA across consecutive waves, teacher support was negatively correlated with LMA at each wave, βs ranged from −0.39 to −0.22, *p*s

< 0.05 **(see Fig. 1B)**. However, in contrast to the previous model, we found some support for the bidirectional associations between teacher support and LMA over time (**see Fig. 1B**). More specifically, teacher support in grades 3 and 5 negatively predicted the subsequent LMA in grades 4 and 6, βs = −0.12 and −0.09, $ps < 0.05$. Furthermore, we found that LMA in grades 3, 4, and 5 negatively predicted the subsequent teacher support in grades 4, 5, and 6, βs ranged from −0.18 to −0.12, $ps < 0.05$. Therefore, hypothesis 1b was supported such that teacher support was negatively associated with LMA both concurrently and predictively over time.

3.3. Test of mediation

Next, we examined the degree to which significant associations between perceived teacher support and the two types of mathematics anxiety were mediated by mathematics learning engagement. **Table 3** presents within-wave covariance estimates for all longitudinal mediation models.

Table 3
Within wave standardized covariance estimations to accompany figure 2A-2B.

Grade 3		Grade 4		Grade 5		Grade 6	
Figure 2A							
PTS↔MLE	0.60^{***}	PTS↔MLE	0.40^{***}	PTS↔MLE	0.27^{***}	PTS↔MLE	0.49^{***}
MLE↔MEA	-0.15^{***}	MLE↔MEA	-0.30^{***}	MLE↔MEA	-0.20^{***}	MLE↔MEA	-0.33^{***}
PTS↔MEA	-0.13^{**}	PTS↔MEA	-0.19^{***}	PTS↔MEA	-0.22^{***}	PTS↔MEA	-0.21^{***}
Figure 2B							
PTS↔MLE	0.60^{***}	PTS↔MLE	0.39^{***}	PTS↔MLE	0.26^{***}	PTS↔MLE	0.48^{***}
MLE↔LMA	-0.16^{***}	MLE↔LMA	-0.30^{***}	MLE↔LMA	-0.26^{***}	MLE↔LMA	-0.41^{***}
PTS↔LMA	-0.22^{***}	PTS↔LMA	-0.33^{***}	PTS↔LMA	-0.36^{***}	PTS↔LMA	-0.35^{***}

Note. PTS = Perceived teacher support, MLE = Math learning engagement, MEA = Mathematics evaluation anxiety, LMA = Learning mathematics anxiety.
*** $p < 0.001$, ** $p < 0.01$.

3.3.1. The mediating role of mathematics learning engagement between teacher support and subsequent mathematics evaluation anxiety

We hypothesized that mathematics learning engagement would mediate the relation between perceived teacher support and MEA (Hypothesis 2a). **Fig. 2A** displays the model that includes mathematics learning engagement as a mediator between perceived teacher support and MEA. The model had a satisfactory fit, $\chi^2(361) = 1832.65$, $p < 0.05$, RMSEA = 0.05, CFI = 0.95, TLI = 0.94, and SRMR = 0.07. We found that perceived teacher support positively predicted the subsequent mathematics learning engagement in the later elementary years (grade 5 to 6), $\beta = 0.20$, $p < 0.001$. Mathematics learning engagement positively predicted the subsequent perceived teacher support across the consecutive waves, βs ranged from 0.14 to 0.25, *ps* < 0.001. In addition, although not showed in the model, perceived teacher support was significantly correlated with student mathematics evaluation anxiety at each time point. Furthermore, mathematics learning engagement negatively predicted subsequent MEA across the consecutive waves, βs ranged from −0.18 to −0.13, *ps* < 0.001. Bidirectional longitudinal associations emerged between MEA and mathematics learning engagement, βs ranged from −0.11 to −0.08, *ps* < 0.01. However, in these fully controlled cross-lagged model, mathematics learning engagement did not emerge as a significant longitudinal mediator between perceived teacher support and MEA at any time point. Specifically, the indirect effects of grades 4 and 5 mathematics learning engagement between the relations of grades 3 and 4 perceived teacher support and grades 5 and 6 MEA were −0.003 and 0.003, 95% CI [−0.016, 0.008] and [−0.007, 0.016] (See **table 4**). Interestingly, mathematics learning engagement in grade 4 significantly mediated the association between MEA in third

grade and perceived teacher support in fifth grade, μ = −0.020, 95% CI [−0.039, −0.005], and effect size = 60.61%. And similar results emerged from grade 4 MEA to grade 6 perceived teacher support, μ = −0.017, 95% CI [−0.031, −0.004], and effect size = 26.79% (See table 4).

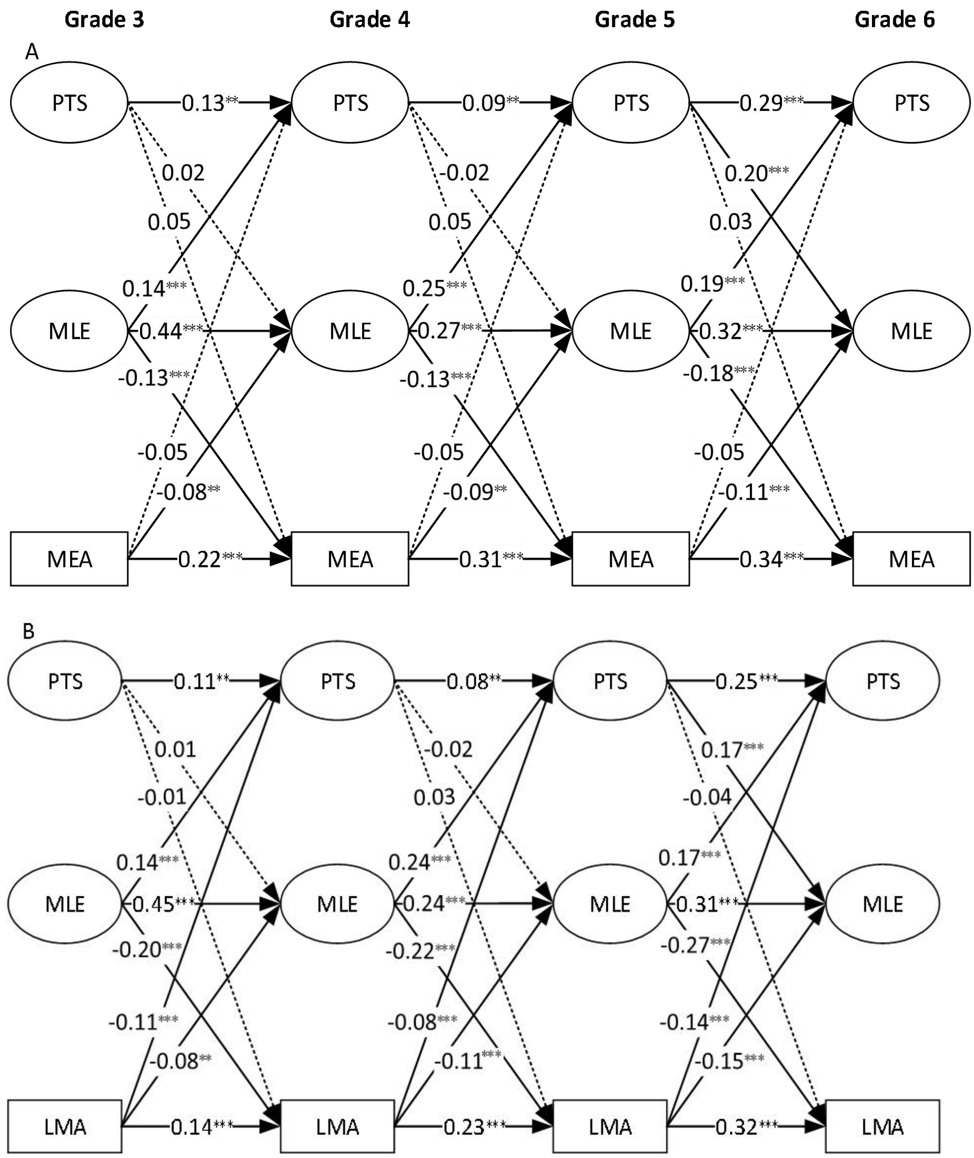

Fig. 2. Cross-lagged path models testing mediation effect of mathematics learning engagement on the relation between perceived teacher support and mathematics evaluation anxiety (A), perceived teacher support and learning mathematics anxiety (B). *Note.* PTS = perceived teacher support, MLE = mathematics learning engagement, MEA = mathematics evaluation anxiety, LMA = learning mathematics anxiety. Perceived teacher support and mathematics learning engagement are latent variables with factor loadings ranging from 0.61 to 0.92 in perceived teacher support

and from 0.73 to 0.95 in math learning engagement. Dotted lines indicate non-significant paths. Within wave covariances are presented in Table 3. Control variables include gender, test anxiety, general anxiety, and math performance. $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 4

Results of indirect effects.

	Indirect effect	*SE*	Effect size	95% CI
From grade 3 to grade 5				
PTS→MLE→MEA	–0.003	0.005	16.67%	[–0.016, 0.008]
MEA→MLE→PTS	–0.020*	0.009	60.61%	[–0.039, –0.005]
PTS→MLE→LMA	–0.001	0.010	25.00%	[–0.022, 0.016]
LMA→MLE→PTS	–0.019*	0.008	50%	[–0.037, –0.004]
From grade 4 to grade 6				
PTS→MLE→MEA	0.003	0.005	12.50%	[–0.007, 0.016]
MEA→MLE→PTS	–0.017*	0.006	26.79%	[–0.031, –0.004]
PTS→MLE→LMA	0.011	0.009	50.00%	[–0.007, 0.028]
LMA→MLE→PTS	–0.018**	0.006	26.87%	[–0.032, –0.008]

Note. PTS = Perceived teacher support, MLE = Math learning engagement, MEA = Mathematics evaluation anxiety, LMA = Learning mathematics anxiety.
$^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

3.3.2. The mediating role of mathematics learning engagement between teacher support and subsequent learning mathematics anxiety

We also hypothesized that mathematics learning engagement would mediate the relation between perceived teacher support and LMA (Hypothesis 2b). **Fig. 2B** displays the model that includes mathematics learning engagement as a mediator between perceived teacher support and LMA. The model had an acceptable fit, $\chi^2(362) = 1849.89$, $p < 0.05$, RMSEA = 0.05, CFI = 0.95. TLI = 0.94, and SRMR = 0.07. As a parallel model to the previous model above, perceived teacher support positively predicted the subsequent mathematics learning engagement only in the later elementary years (grade 5 to 6), $\beta = 0.17$, $p < 0.001$. Mathematics learning engagement positively predicted the subsequent perceived teacher support across the consecutive waves, βs ranged from 0.14 to 0.24, *ps* < 0.001. Mathematics learning

engagement negatively predicted subsequent LMA significantly and incrementally at each time point, |β|s ranged from 0.20 to 0.27, *ps* < 0.001. Bidirectional paths also emerged between LMA and mathematics learning engagement, βs ranged from −0.15 to −0.08, *ps* < 0.001. Unlike the previous model, LMA significantly predicted perceived teacher support at each time-point, βs ranged from −0.14 to −0.08, *ps* < 0.001. Furthermore, we found that mathematics learning engagement in grade 4 mediated the relation between LMA in grade 3 and perceived teacher support in grade 5, μ = −0.019, 95% CI [−0.037, −0.004], and effect size = 50.00% (See **Table 4**). Similarly, mathematics learning engagement in grade 5 mediated the relation between LMA in grade 4 and perceived teacher support in grade 6, μ = −0.018, 95% CI [−0.032, −0.008], and effect size = 26.87% (See **Table 4**). However, mathematics learning engagement did not emerge as a significant longitudinal mediator between perceived teacher support and LMA at any time point. Therefore, Hypothesis 2b was partially supported that mathematics learning engagement mediated the relation between early LMA and subsequent perceived teacher support, but not mediated the relation between early perceived teacher support and subsequent LMA.

4. Discussion

The development of mathematics anxiety is assumed to be related to both individual (mathematics learning engagement) and environmental (perceived teacher support) factors (Maloney et al., 2015; Rubinsten et al., 2018). However, the dynamic interplay among mathematics anxiety, perceived teacher support, and mathematics learning engagement for elementary school students is not well understood. To

address this issue, in the present study we tested a longitudinal cross-lagged model for Chinese students from grade 3 to 6.

4.1. Bidirectional influences between teacher support and mathematics anxiety varied by mathematics anxiety dimensions

The two dimensions of mathematics anxiety yielded different patterns of results in relation to teacher support. First, as expected (Hypothesis 1a), we found that teacher support was concurrently negatively related to MEA in each grade, which is inline with previous research(Li et al., 2021). The negative relation between teacher support and MEA is possibly explained by students' feelings of control, autonomy, and mathematics attitudes. Support provided by mathematics teacher strengthens the emotional connection between teachers and students by valuing students' opinions and supporting and empathizing with students' coping with stress. These are associated with students' feelings of control and autonomy, which in turn reduce students' anxiety about tests (Pekrun, 2007; Pekrun et al., 2017). Going beyond these initial findings, our study indicated that there was lack of longitudinal associations from teacher support to MEA across time. More specifically, teacher support from grade 3 to 5 did not predict subsequent MEA from grade 4 to 6. This may be because the negative affect that accompanies MEA (relative to LMA) is associated with situations in which children are specifically being evaluated on mathematics-related tasks, suggesting the negative affect is transitory in nature and is a form of expression of state anxiety (Chen et al., 2015; Garcia et al., 2013). Or MEA may be more malleable than previously believed (Jamieson et al., 2016), students' anxiety about

examinations was relieved by teacher immediate support. On this view, teacher support was only concurrently, not longitudinally, associated with MEA. Namely, teacher support may have an immediate rather than long-lasting effect on MEA. Notablely, our study showed that MEA negatively predicted subsequent teacher support. We favor the possibility that students with high MEA may worry about all kinds of potential criticize in math from others. Thus they would show more avoidance tendency whereas students with low MEA would actively seek help from teacher. This view is supported by control-value theory of achievement emotions assumed that achievement emotions act back on environmental (Pekrun et al., 2007; Pekrun, 2017).

Unlike MEA, we found that teacher support was related to LMA concurrently and longitudinally (see also in Li et al., 2021). More specifically, we found bidirectional associations between teacher support and LMA from grade 4 to 6. This is inline with Hypothesis 1b and support control-value theory of achievement emotions (Pekrun et al., 2007) that environmental factors and emotions are thought to be linked reciprocal causation over time. On the one hand, this finding suggests that students who perceived more teacher support are less likely to develop LMA than those who perceived less guidance and support in the later grades of elementary school. One possible explanation is that teacher support by guiding the acquisition of knowledge and skills, as well as providing the autonomous support and cognitive support that directly targets students' schoolwork and new content for students to feel capable of learning may largely facilitate students' efficacy (Liu et al., 2018) and influence

mathematics attitude (Dietrich et al., 2015; Ober et al., 2021) in learning. For example, when a math teacher attends to the process of how students solve the problems and provides help to students, students will be more confident to overcome obstacles and experience less anxiety in learning. On the other hand, LMA also contributed to teacher support from grade 4 to 6, suggesting that students who reported experiencing lower level of LMA were willing spend more time studying mathematics and actively sought help from teachers when encountering problem such that teachers were more likely to provide support when their students actively sought help.

4.2. The mediation role of mathematics learning engagement in the link between perceived teacher support and mathematics anxiety

Surprisingly, hypothesis 2a and 2b were partially verified. We hypothesized that mathematics learning engagement would mediate the relation from teacher support to mathematics anxiety (including MEA and LMA, the same as below) and the relation from mathematics anxiety to teacher support. Based on the longitudinal cross-lagged mediation analyses, we found that fourth-graders' mathematics learning engagement mediated the relation between third-graders' LMA and fifth-graders' perceived teacher support. Similarly, fifth-graders' mathematics learning engagement mediated the relation between fourth-graders' LMA and sixth-graders' perceived teacher support. In contrast, mathematics learning engagement did not mediate the relation from perceived teacher support to subsequent LMA in any grade. The same patterns of results were found in the relation between perceived teacher support and MEA. In regards of the relation from mathematics anxiety to perceived teacher support, our

results indicated that students with low mathematics anxiety enhanced mathematics learning engagement, which in turn increased teacher support. These results correspond to the assumptions of Pekrun and colleagues (2007) who state that academic emotions influence academic engagement. Students with more positive mathematics emotions (e.g., enjoying mathematics or feeling competent in mathematics) showed more engagement of hippocampus learning system and thus they tended to put more effort in learning mathematics (Chen et al., 2018; Luo & Luo, 2022). In contrast, students with more negative mathematics emotions (e.g., mathematics anxiety) tended to avoid mathematics class and had less engagement in learning mathematics (Pinxten et al., 2014). If a student with low mathematics anxiety, for example, it may be easier for him to complete assignments. Furthermore, our results revealed that students' mathematics learning engagement affects teachers' support. One possibility is that students with high level of mathematics learning engagement are more likely to spend extra effort and time into learning activities, such as studying materials in advance of class and thoroughly comprehending more complex mathematics concepts. These students presumably need additional guidance and support from their teachers (Schunk, 2012). And thus they may engage in positive interactions with the teacher and tend to elicit more positive teacher responses. In contrast, students with low level of mathematics learning engagement are less likely to seek help with homework and they also tend to avoid eye contact with the teacher in class (Turner et al., 2002), which may make it more difficult for teachers to support these students as mathematics difficulties may go unnoticed. This view is supported

by control-value theory of achievement emotions (Pekrun et al., 2007) that achievement emotions influence learning behavior (i.e., learning engagement), and the process of learning is expected to act back on environment (i.e., teacher support). Both theoretical and empirical studies emphasize the important role of mathematics learning engagement in the relation between mathematics anxiety and teacher support. Therefore, it is possible to consider a school-based intervention on elementary students' learning engagement. A recent research revealed that intervention enhanced students' cognitive, emotional, and behavioral engagement, moreover, boys benefited more from intervention than girls (Azevedo et al., 2023).

In regards of the relation from perceived teacher support to mathematics anxiety, our study showed that mathematics learning engagement may help students cope with anxiety that stems from mathematics evaluation situations and the process of learning mathematics, which is in line with previous research (Aldrup et al., 2020; Lietaert et al., 2015). However, our results indicated that teacher support did not predicted subsequent mathematics learning engagement and mathematics anxiety except the relation between 5 graders' teacher support and 6 graders' mathematics learning engagement, which seems inconsistent with previous studies that revealed teacher support was related to learning engagement (Hospel & Galand, 2016; Lietaert et al., 2015; Liu et al., 2018) and emotion (Hospel & Galand, 2016; Pekrun et al., 2017). We make an attempt to give potential explanations. But in fact, previous research examined the relation between teacher support and learning engagement, teacher support and academic emotions from cross-section perspective not longitudinal

perspective. Thus they cannot reveal longitudinal relation between teacher support, learning engagement, and academic emotions. To our knowledge, in a longitudinal study, Dietrich and colleagues (2015) indicated that teacher support in grade 5 was negatively related to students' effort (like behavior engagement) in grade 6, which is in line with our results. Therefore, we speculated that a stable longitudinal connection between teacher support and students' learning engagement may emerge in the later stages of elementary school (Dietrich et al., 2015), which needs further examination and discussion. This view does not mean that teacher support was not important for students' subsequent learning behavior and academic emotions in the early stages of elementary school. Teacher support could not predict subsequent mathematics learning engagement and mathematics anxiety directly but could predict subsequent mathematics learning engagement and mathematics anxiety indirectly through current learning engagement and mathematics anxiety respectively. Another possible explanation was that students in this study were reassigned into a new class when they came to higher grades. And they may have new teachers. Therefore, previous teachers have little impact on the learning and behavior of current students. This also prompts us to reflect on whether frequent class adjustments are meaningful for students' learning.

Taken together, our study extend previous theoretical work (Pekrun et al., 2007; Rubinsten et al., 2018) by showing differential relations between the two basic dimensions of mathematics anxiety defined by Hopko et al. (2003) and teacher support and students' learning engagement. Our findings highlight the importance of

perceived teacher support in promoting mathematics learning engagement and to reduce anxiety in classrooms for students. More importantly, mathematical anxiety would lead to a decrease in mathematical learning engagement and even avoidance of teacher support and assistance.

4.3. Limitations and future directions

The present study has two limitations. First, prior studies demonstrated that mathematics anxiety in early elementary school is associated with teachers' attitudes and behaviors (Beilock et al., 2010; John et al., 2020). For example, teachers who are anxious about their own mathematics skills can potentially pass their negative attitude about mathematics to their students (Maloney & Beilock, 2012). Moreover, teachers' mathematics anxiety was most strongly related to the mathematics anxiety of their low-SES students (McLean et al., 2023). Thus, future research should take teacher's mathematics anxiety into account when investigating the association between perceived teacher support and mathematics anxiety. Second, participants in this research were from three schools in two towns and they were mainly from the low-middle SES group in China. Therefore, this study cannot be generalized to all elementary school students in different school settings due to the potential differences of public school environment and mathematics content across regions. Replicating the findings of the present study in diverse learning environments with a sample of students from diverse developmental, social, economic, and ethnic backgrounds is necessary.

4.4. Practical implications

The findings of the present study have significant implications. First, the present study takes the initiative in exploring the differential dimensions of mathematics anxiety in elementary school. Thus, educators and researchers should be aware of the existence of differences in the influencing factors of the dimensions of mathematical anxiety, which is vital in the design and development of an intervention program (Jamieson et al., 2016). For example, MEA can be reduced by expressive writing (Ramirez & Beilock, 2011) and reappraising stress arousal (Jamieson et al., 2021). In contrast, LMA can be decreased by positive mathematics value (John et al., 2020) and mathematics strategy training (Passolunghi et al., 2020).

Second, our results highlight the importance of the role of teacher support and learning engagement on students' development of mathematics anxiety, especially the long-term effect of negative emotions (i.e., mathematics anxiety) on individual learning behavior and environment. More specifically, interventions should focus on the role of teacher support and when this support can foster students' academic and emotional development (Aldrup et al., 2020; Martin & Collie, 2019). Moreover, for the long-term development of students, their academic emotions cannot be ignored.

In summary, the present study is the first one to provide insight into the complex interplay among perceived teacher support, mathematics learning engagement, and mathematics anxiety in a large sample from elementary school in China by using of long-term longitudinal data from four time points. These findings will be of interest to researchers and educators, who could develop further interventions to help students reduce negative emotions and the effect of negative emotions about mathematics on

environment (e.g., teacher-student interaction) and individual behavior.

5. Conclusions

The purpose of the present study was to investigate the longitudinal relation among perceived teacher support, mathematics learning engagement, and mathematics anxiety. In summary, our findings suggest that the bidirectional relations between teacher support and mathematics anxiety varied by dimensions of mathematics anxiety in Chinese students across grade 3 to grade 6. Furthermore, both MEA and LMA reduced students' subsequent mathematics learning engagement, which in turn enhanced teacher support.

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